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ULTRASONIC WELDING PROCESS AND EQUIPMENT FOR CONSTRUCTION OF ELECTRON-TUBE MOUNTS

Contract No. DA-36-039-sc86741
Order No. 19063-PP-62-81-81

Placed by
Industrial Preparedness Activity
United States Army Electronics
Materiel Agency

AEROPROJECTS INCORPORATED
West Chester, Pennsylvania

ULTRASONIC WELDING PROCESS AND EQUIPMENT FOR CONSTRUCTION OF ELECTRON-TUBE MOUNTS

First Quarterly Progress Report
For the Period
June 27, to September 30, 1962

The object of this program is to design and construct prototype welding equipments and their associated accessories to perform by ultrasonic techniques the welding operations required in the assembly of electron tubes under Specifications SCS-114A and SCIPPR-15.

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Report Approved by: Byron Jones

ABSTRACT

The purposes of the program are outlined. The fundamentals of the ultrasonic welding process are briefly presented. Ultrasonic welding equipment of the types and sizes relevant to this program is described. Problems encountered in the resistance welding of electron-tube mounts are discussed, and compared in kind with ultrasonic welding. Progress in material procurement, as well as in tooling and testing for the weld-study task, are reported. The component assembly sequences of three electron tubes, together with accompanying cataloging of welds, are shown.

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PURPOSES

The objectives of this Production Engineering Measure (PEM) are to:

1. Demonstrate the capability limits of ultrasonic welding to join combinations of metallic materials of interest to the electron-tube industry. This part of the work will be limited in that it will not continue exhaustive attempts to weld those combinations which might prove particularly difficult to join.

2. Analyze the welding requirements for three specific electron tubes. The three tube types selected are the Type 6080WB, 5814WB and 6205. These were selected by the U. S. Army Electronics Materiel Agency because they are widely used in military equipment, and have a record of failures due to improperly welded joints.

3. Prepare fixturing and tooling for the specific electron tubes, so that ultrasonic welding may be used in the manufacturing process.

4. Weld the parts required to assemble electron-tube mounts for the three tube types, and evaluate.

5. Build production ultrasonic welding equipment which will enable an electron-tube manufacturer to make the welded connections in a broad range of electron-tube types.

6. Install the ultrasonic welding equipment in a production company, and produce on a pilot basis with that company's personnel, a limited lot size of each of the three tubes for subsequent evaluation in accordance with applicable military specifications.

NARRATIVE AND DATA

THEORY OF ULTRASONIC WELDING

The mechanism of ultrasonic welding is not completely understood (1,3,4)*. However, fundamental research has described some of the phenomena which occur during the operation of the technique. All welding processes are based upon the fact that metal atoms with unsatisfied electron structure are capable of bonding to other atoms if they are brought into contact. If two absolutely smooth, clean metallic surfaces are brought together, the unsatisfied electron structure of the atoms of both surfaces will join to create a true metallurgical bond.

Ordinary metallic surfaces are prevented from forming such true metallurgical bonds because of surface irregularities, the adhered moisture layer, and the oxide film, which are illustrated in Figure 1. A superfinished surface normally has irregularities that average about 200 atomic layers in depth. The strong attractive forces of the surface metallic atoms attract and hold oxygen molecules from the atmosphere surrounding the surface, reacting to form oxides. At thicknesses of approximately 200 molecules, the oxide films are crystalline, and have surface molecules with unsatisfied bonds like the atoms of the free metallic surface. The metallic oxide molecules exert only weak attractive forces upon symmetric molecules such as oxygen, but somewhat stronger forces upon asymmetric molecules such as water vapor. Therefore, a film of condensed adsorbed moisture, never less than two or three molecules thick, is formed on the oxide metal surface. These barriers prevent contact between atoms with incomplete molecular shells, and must be removed to create a welded joint. The ultrasonic welding process causes a large contact area between nascent metal surfaces by plastically deforming the interface between the workpieces so that the adhered moisture and oxide films are dispersed, and the irregular surfaces are made contiguous.

A supplementary phenomenon in the ultrasonic welding process is a temperature rise resulting from the elastic hysteresis of the highly stressed portion of the weld zone. Laboratory investigations show that the maximum transient temperature at the weld interface in a monometallic joint is between 30 and 50 percent of the absolute melting point of the metal. Since this temperature rise is highly localized, there is only a small temperature rise in the weldment. The temperature rise in the weld zone does temporarily increase the ductility of the metal, and promotes plastic deformation.

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* Numbers in parenthesis refer to references listed at end of report.

Another phenomenon is plasticization from the high-frequency mechanical vibration per se. When the stresses resulting from the clamping force and the super-imposed vibration reach the elastic limit of the material being welded, the material near the interface will undergo plastic deformation. The block diagram, Figure 2, summarizes the foregoing theoretical model of the ultrasonic welding process.

These facts merely outline some of the fundamental aspects of the ultrasonic welding process. More detailed study of the mechanism of ultrasonic welding, including the concepts of maximum supportable lateral shear stress and interfacial micro slip, are reported elsewhere (4).

ULTRASONIC WELDING EQUIPMENT

Welding is accomplished by clamping the workpieces between a sonotrode, or active tip, and an anvil, so that the material experiences the stresses resulting from the clamping force and the super-imposed vibration of the sonotrode. The heart of all ultrasonic welding equipment is the transducer-coupling system which converts electrical energy to vibratory energy and delivers it to the weldment. Commercial equipment utilizes magnetostrictive transducers wherein elastic vibration comes from the rapid expansion and contraction of laminated nickel under the influence of a high-frequency alternating magnetic field. These elastic waves travel along the coupler to the sonotrode tip which contacts the workpieces. The sonotrode tip excursion is parallel to the surfaces of the weldment, and induces a shear mode of vibration into the workpieces.

The initial phase of this program will be carried out on available models of the 100-watt, 600-watt and 4-kw ultrasonic welders which are similar to the commercial welders shown in Figure 3. Each piece of equipment consists of an ultrasonic welding unit and properly matched power source. Each welding unit incorporates a transducer-coupling tip assembly, an anvil or work support for the workpiece, force-application system, timing device, and essential controls. The transducer-coupling systems are supported by unique force-insensitive mounts, which minimize energy loss to the supports, and insure constancy of operating characteristics under high-clamping forces. "Screw-on" welding tips for the two smaller units permit simple tip interchangeability. On the 4-kw machine, the sonotrode tip is attached with a braze joint. The anvils on all machines are removable for substitution of special-purpose tooling and fixturing by removing several standard machine bolts. The stroke on the 600-watt welder is variable to a maximum of 1-1/2 inches, and the 4-kw unit stroke to a maximum of 3-1/2 inches by turning a screw adjustment.

Operating controls for ultrasonic welding machines are simple and easily understood. Quality welding is accomplished with adjustments in only three machine settings: power, clamping force, and weld time. Previously established machine settings can be reset by relatively unskilled personnel.

Dials on the power source provide easy means for duplicating power level settings previously established as satisfactory.

Clamping force, which secures the weldment members in position and insures good coupling of vibratory energy into the weldment, is applied hydraulically or with mechanical springs. The clamping force devices are calibrated for reproducibility. Clamping force requirements for welding various metals and thicknesses may vary from several grams with the small welder to 1200 pounds with the larger unit.

The duration of the spot-weld interval is controlled by standard adjustable electronic timers. Weld times usually vary from 0.1 second to about 1.5 seconds.

For standard manual operation, the complete welding cycle is iniated by depressing a foot switch. The welding tip clamps the workpiece, the ultrasonic welding pulse fires when the proper clamping force has been reached, then the welding tip retracts and the circuitry resets for the next operation. It is a simple matter to rearrange the control circuit so that all welding operations are initiated by automatic mechanical handling devices, and an automated production process is obtained.

A range of materials and thicknesses can be joined by the same welding machine by varying the combinations of power, clamping force, and weld time. The size of the welder, however, must be compatible with the application to permit the best control over the process.

The equipment fits easily into production lines because of the low-power requirements, portability, and the ease with which the power source may be remotely located from the welding head.

WELDING PROBLEMS IN THE ELECTRON-TUBE INDUSTRY

Resistance welding is the principal manufacturing process employed in the electron-tube industry for the welding of components. Resistance welders are relatively low in cost, and by virtue of use-familiarity by manufacturing personnel, have acquired industry acceptance over the years.

Despite the acknowledged usefulness of the process, resistance welding is known to have a number of intrinsic deficiencies. It is one of the prime purposes of this investigation to consider these deficiencies in the light of rectification by the use of ultrasonic welding. The isolation below of some of the reported welding problems within the electron-tube manufacturing industry is not in any way intended as a condemnation of a well-accepted manufacturing technique.

The reproducibility of resistance welding is affected by the surface resistivity between both the materials themselves, and the welding tips and the materials. Factors which bear upon surface resistivity are material cleanliness, welding jaws pressure, and welding tip condition. It is recognized that extreme care in material cleaning is exercised within the industry, to insure proper electron-tube performance. Nevertheless, the circumstances of ordinary storage and handling of electron tube parts can produce variations in surface conditions which markedly influence both welding quality and reproducibility.

On the other hand, ultrasonic welding does not demand critical surface cleaning of materials, since no electrical conductivity is involved and the vibratory displacements which occur during the welding process disrupt the surface films. The normal cleaning processes and handling procedures currently practiced to maintain electron-tube quality should be adequate for the ultrasonic method. As far as reproducibility is concerned, it has been reported that production yields for ultrasonic welding have been "beyond reproach" (2).

An additional problem with resistance welding is the necessity for welding-tip refurbishment at frequent intervals, so that a contact condition which will reproduce quality welds can be maintained. Ultrasonic welding tips, however, are generally made from hardened tool steel, and have a more or less indefinite service life under many conditions. It is expected, therefore, that welding tip maintenance in ultrasonic welding will not present serious problems.

Within the electron-tube industry, components are designed to locate properly each to the other, or to be "self-jigging." As a result, they can be welded with a minimum of fixturing, with the operator locating the work in the welding jaws by sight. Ultrasonic welding dictates that work be more carefully located in relation to the welding tip, requiring more extensive although uncomplicated locating fixturing.

It is difficult to resistance weld materials with comparatively high coefficients of electrical or thermal conductivity, such as aluminum, copper, silver, etc. And when welding dissimilar metals and/or dissimilar thicknesses, such variables are difficult to bring under proper control. If the magnitude of electric current is not regulated properly, for instance, welds will be burned, or insufficiently fused. Ultrasonic welding is not restricted by such factors, since no electrical current is required. The technique is affected when joining dissimilar metals, however, by the relative hardness of the materials to be joined (4). Welding becomes more difficult to accomplish as the difference in the hardness of the materials becomes greater. Differences in geometries, such as welding wire to flat, may accentuate the effect of the hardness difference. For example, the influence of vibratory energy will tend to embed a hard wire into a soft, flat material and not form a bond.

The sparking and spatter which is common to resistance welding frequently burns operators' clothing, and cracks glass parts. More importantly, it creates small metal particles which temporarily adhere to the assembly, subsequently floating and short-circuiting the tube during operation. Ultrasonic welding creates none of these problems.

Deformations in the order of 35 percent are characteristic of resistance welding. In flat materials, ultrasonic welds have deformations of less than 5 percent. Wire-welding deformations may, however, approach those of resistance welds.

Resistance welds have cast structures, often with oxide inclusions, which increase resistance and produce brittleness. On the other hand, ultrasonic welds are solid-state metallurgical bonds (1), creating no substantial change in properties in the parent metal. Significant increases in shock resistance and lower joint resistivity have been reported by industry users (2). The difference between an ultrasonic weld and a resistance weld is dramatically illustrated in Figure 4, which shows an ultrasonic weld in 0.050-inch-thick Alclad aluminum alloy and a resistance weld in similar material 0.040-inch thick. Contrast the cast zone of the resistance weld with the solid-state bond of the ultrasonic weld.

Resistance welding usually requires the joint area to be heated to the melting temperature of the materials. Such heat requirements will frequently distort components, and because of the precise clearances in tube parts, will reduce manufacturing yields. Although there is a local temperature rise in ultrasonic welding, the increase is seldom sufficient to distort workpieces.

Atmosphere protections by such techniques as flooding the weld area with hydrogen or by immersing the parts in carbon tetrachloride are necessary to prevent some material combinations from oxidizing during resistance welding. Such measures are not often requisite with ultrasonic welding.

Since ultrasonic welding uses vibratory rather than electrical energy to produce a weld, it is considered a new manufacturing tool. As with any new process, it will take a considerable time period before manufacturing personnel can become familiar with and fully understand its complete range of capabilities and advantages. It will be necessary also for designers to become conversant with the method, so that they may extend their designs by utilizing the potentials of the new technique. Further extensions in the ability to weld dissimilar metals, dissimilar thickness, and very-low-thickness materials will doubtless prove advantageous in the electron-tube manufacturing industry.

Ultrasonic welding has already demonstrated specific advantages in metal joining. Two problems which may be involved in the use of ultrasonic welding equipment are weld-area accessibility to the sonotrode (the active welding tip), and fixturing to hold work in proper relationship to the sonotrode. As the welding tip is part of an acoustical member, its size and shape cannot be changed at will, underlining to some degree the factor of accessibility.

WELDING STUDY

The program specifies the welding of metal combinations shown in Figure 5, (metals commonly utilized in electron-tube manufacture), and evaluating the welds in accordance with pertinent provisions of MIL-W-6858. It is apparent that the range of materials is of sufficient scope to include easy-to-weld, and difficult-to-weld combinations. In conformance with the requirements of the work, this phase of the program must of necessity be limited, since the over-all objective is the building and installation of ultrasonic equipment for production manufacture of electron tubes. Material combinations proving difficult to weld with normal expenditures of time and effort will not be pursued further. Test specimens are to be of lap-joint configuration, and will include attempted junctions in 51 material combinations. In each combination, wire sizes of 0.0003-inch diameter and 0.060-inch diameter will be welded to 0.060-inch flat sheet material. Material gages of wires and flats are to be to the nearest commercially available sizes.

Tensile-shear strength data will be compiled on all specimens which are welded successfully. The procedure for the other tests to be performed on these weldments is being altered and will be included in the next report.

Activity within this study will fall into the following classifications:

1. Material Procurement
2. Tooling (testing and welding fixtures)
3. Welding
4. Welding Evaluation.

1. Material Procurement

Time-consuming procurement difficulties were encountered in securing wire and flat sheets in the sizes stipulated, particularly the wire as close to 0.0003-inch as possible. The limited quantities required, plus the fact that the program could not underwrite the cost or time delay of specially processed materials, were factors contributory to purchasing road-blocks. Delivery of the bulk of the materials was not made until the end of this report period, so no real welding effort was begun within the period.

Cost considerations led to the establishment of a welding plan wherein more than one weld joint will be made upon a single specimen coupon, set up to measure 1 inch x 3 inches. Materials which could not be cut or sheared with equipment available in our facility were ordered cut to size.

Table 1 shows the wire size quotations secured from 18 suppliers, and the companies from whom the wire was utimately purchased. Table 2 summarizes the sizes of the small-diameter wire which will be used in the program.

It is not at all unlikely that additional problems in the use of small wires may arise as the welding tests begin. An example of the type of difficulty met was the receipt of 0.0003-inch silver wire with a copper cladding too thick to be removed by a feasible etching process. Attempts are being made to secure a new suitable shipment of silver wire.

The specific "mild steel" material procured was:

0.062-inch flat, CRS, 1010, annealed
0.062-inch diameter wire, bright basic wire C-1010
0.0015-inch diameter mild steel wire, .05C

The specific "stainless steel" material procured was:

0.062-inch flat, type 302, annealed
0.062-inch diameter wire, type 304, annealed
0.001-inch diameter wire, type 302, annealed

Identification, storage, and control of the many material combinations without error is essential. A technique utilizing small-compartment storage cabinets was established, and such cabinets purchased.

2. Tooling for Wires to Flats

The tooling for the welding study can be classified as: 1. testing fixtures, 2. welding fixtures.

The actual parent-metal strengths of each wire size and material have to be determined to provide a basis for evaluating the strength of the welded joints. The welded joints must also be tested in tensile shear. This is done on an Instron testing machine, shown in Figure 6, which has a wide range of load and pulling-rate ability, together with providing an automatic record of the values obtained. Fixtures are designed and constructed for use with the Instron machine to test the strength of the wires and the welded joints. Standard fixtures did not appear to be practical, especially for brittle wires.

The small-diameter wires were divided into groups of high and low strengths. The small-diameter low-strength wires were tested using commercial jaws with a 50-gram load cell as shown in Figure 7.

Small-diameter high-strength wires require specially designed jaws as shown in Figure 8. The tightening screws in the upper and lower jaws are located to provide a progressive gripping of the wire, and to prevent indentation or high-stress areas which would give inaccurate failure values. In addition, heavy hard paper was used between the jaws and the wire to eliminate slippage.

Jaws for tensile testing the 0.060-inch-diameter wires were made as shown in Figure 9, with the same arrangement used for progressive gripping. However, these jaws are grooved to obtain better wire contact with minimum deformation.

The lower jaw shown in Figure 10 was made to hold the wire-to-coupon weldments for tensile-shear testing. This jaw design will permit testing welded joints that are side by side on the same coupon. The upper jaws for each of the wire-strength classifications will be the same as those listed above for the parent-metal wire strength determinations.

A welding fixture for use on the 4-kw and the 600-watt welders is shown in Figures 12 and 13. The parts must be held without movement during welding on these higher-power machines. In addition, it is necessary to locate the wire accurately in relation to the sonotrode tip, so that the energy distribution is symmetrical.

It is possible that no special fixturing will be required for weldments using the small-diameter wires. Testing to determine the extent of tooling for these welds was started at the end of this report period.

3. Welding

Welding will begin at the start of the next report period, as most of the materials was not received until the end of this report period.

4. Welding Evaluation

Actual parent-metal strengths of the wires were determined on those wires which had been received. The results of these tests are shown in Table 3. The values shown are the average of testing three specimens of each item.

ELECTRON-TUBE STUDY

Chatham Electronics, Division of Tung-Sol Electric Company, Livingston, New Jersey, was selected to assist Aeroprojects Incorporated in completing the program. Their work will involve the evaluation of ultrasonic welding applicable to electron-tube manufacture. Chatham personnel visited Aeroprojects Incorporated, and agreement was reached on a sub-contract which will be executed in the beginning of the next report period.

Conflicting vacation schedules and plant shutdown prevented actual liaison with Chatham until the early part of August.

Mr. Norman Helmstetter was selected by Chatham Electronics as the engineer responsible for coordinating Chatham's activities in this program.

Tung-Sol manufactures the three tube types selected for this program: Type 6080WB at Chatham, Type 6205 at Washington, New Jersey, and Type 5814WB at Bloomfield, New Jersey. Although these tubes are manufactured at several locations, all ultrasonic welding will be done at Chatham using electron-tube parts obtained from their production operations and, where possible, processed under present production conditions.

The three tube-production lines were visited, and manufacturing problems discussed with engineering personnel. Some of the problems mentioned heretofore were defined during these visits.

Drawings and pilot parts for the three electron tubes were obtained from Chatham. These parts have been set out in their assembly sequence as shown in Figures 14, 15 and 16. Welds have been cataloged as shown in the accompanying legends in Tables 4, 5 and 6.

Mechanical strength is the main criterion of welding in these particular electron-tube types. Visual inspection and occasional testing by pulling with tweezers are the only weld checks made during production. After complete assembly and evacuation, the electron tubes are 100-percent electrically tested under a statistical sample plan for vibration and shock. An indication of the manufacturing problems presented by welding is shown in Table 7. These numbers are obtained from completed electron tubes only, and do not include those joints which had to be reworked, and which did not reach final assembly and inspection.

In the next report period, the welding sequences herein described will be analyzed so that the assemblies can be resequenced for ultrasonic welding. No electron tube redesign is contemplated. Change of component position is limited by potential short circuits and changing capacitance or resistance.

After such study, tools and fixtures will be made to ultrasonically weld the actual electron-tube components, and welding will be attempted wherever practical. As work progresses with these electron tubes in continued liaison with Chatham, more understanding of electron-tube welding problems will be gained, and the contribution of ultrasonic welding more fully exploited.

CONCLUSIONS

This program has not advanced sufficiently for categorical statements to be made regarding the degree of contribution which ultrasonic welding may make to better performance and extended service life of electron tubes by means of improved welds. However, prior investigation coupled with initial activities within this program currently indicate that such a contribution may be made. It is further suggested that the ultrasonic welding process and equipment are adaptable to electron-tube production manufacture, with attendant advantages.

PROGRAM FOR THE NEXT REPORTING PERIOD

The weld-study phase of the program will be continued, and welding of the various metal combinations will be initiated. Successful welds will be evaluated. The three selected electron tubes will be reviewed for the application of ultrasonic welding, and specialized tools for such welding will be designed and built.

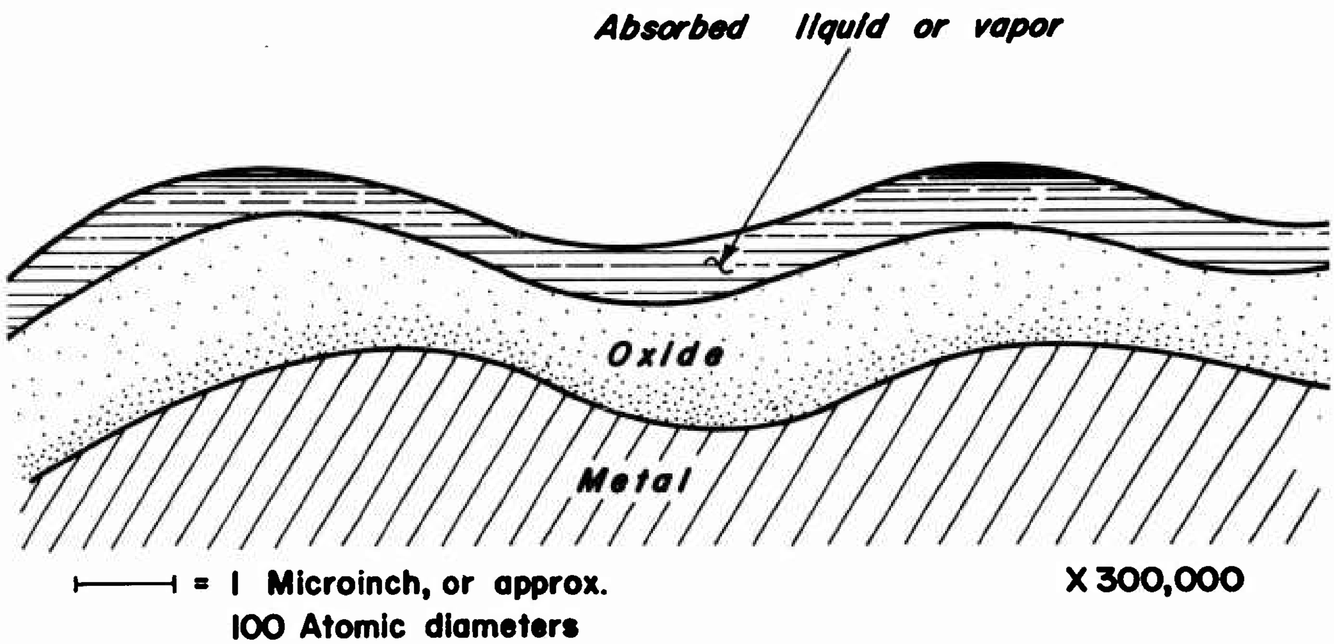


Figure 1

SCHEMATIC REPRESENTATION OF A
SMOOTH CLEAN METAL SURFACE

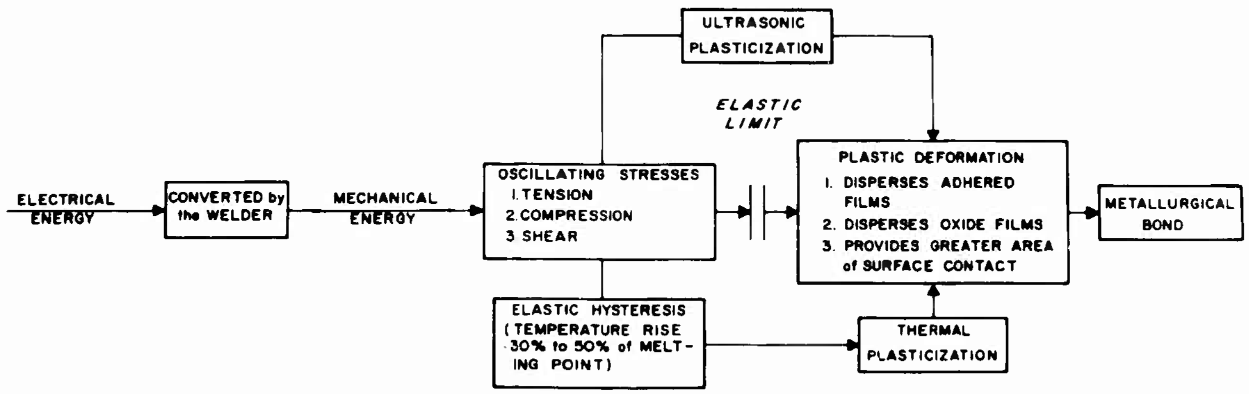
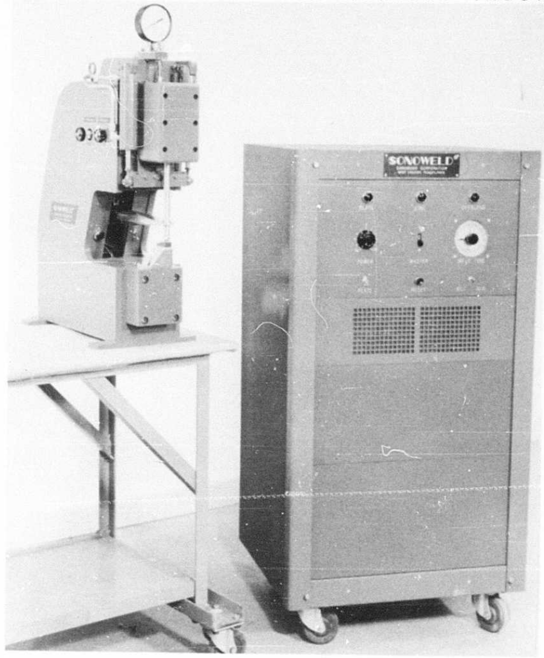


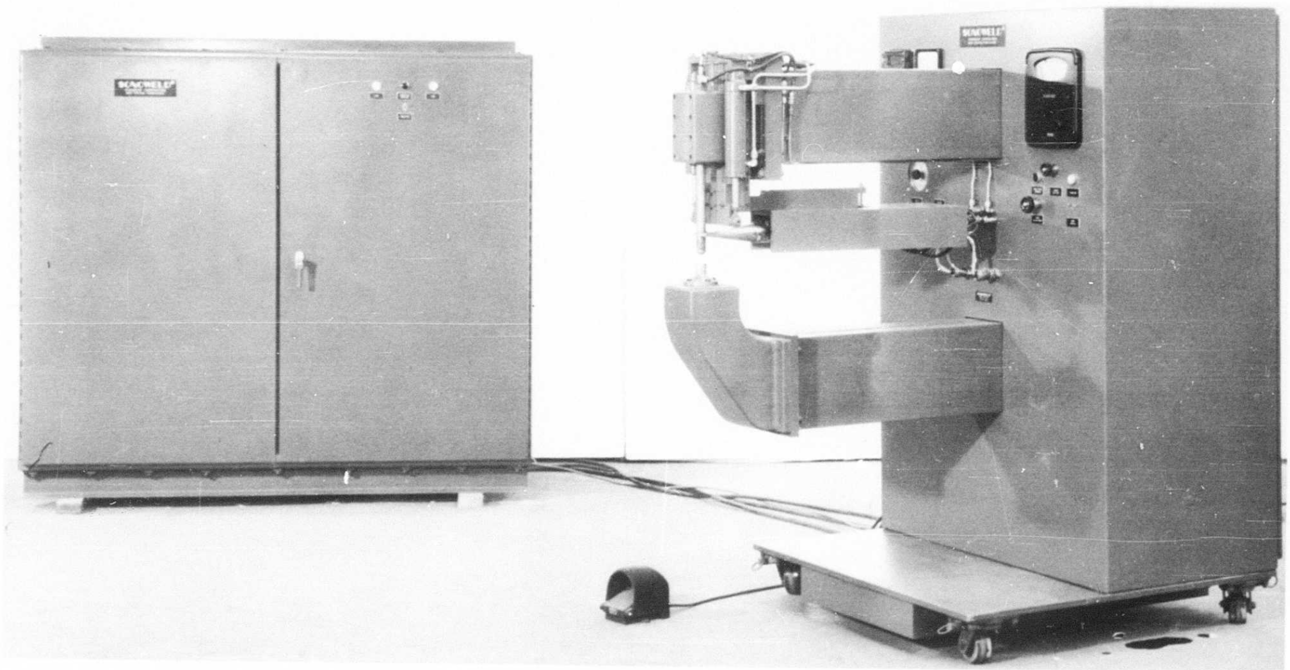
Figure 2

BLOCK DIAGRAM OF THE ULTRASONIC WELDING PROCESS

100-watt welder



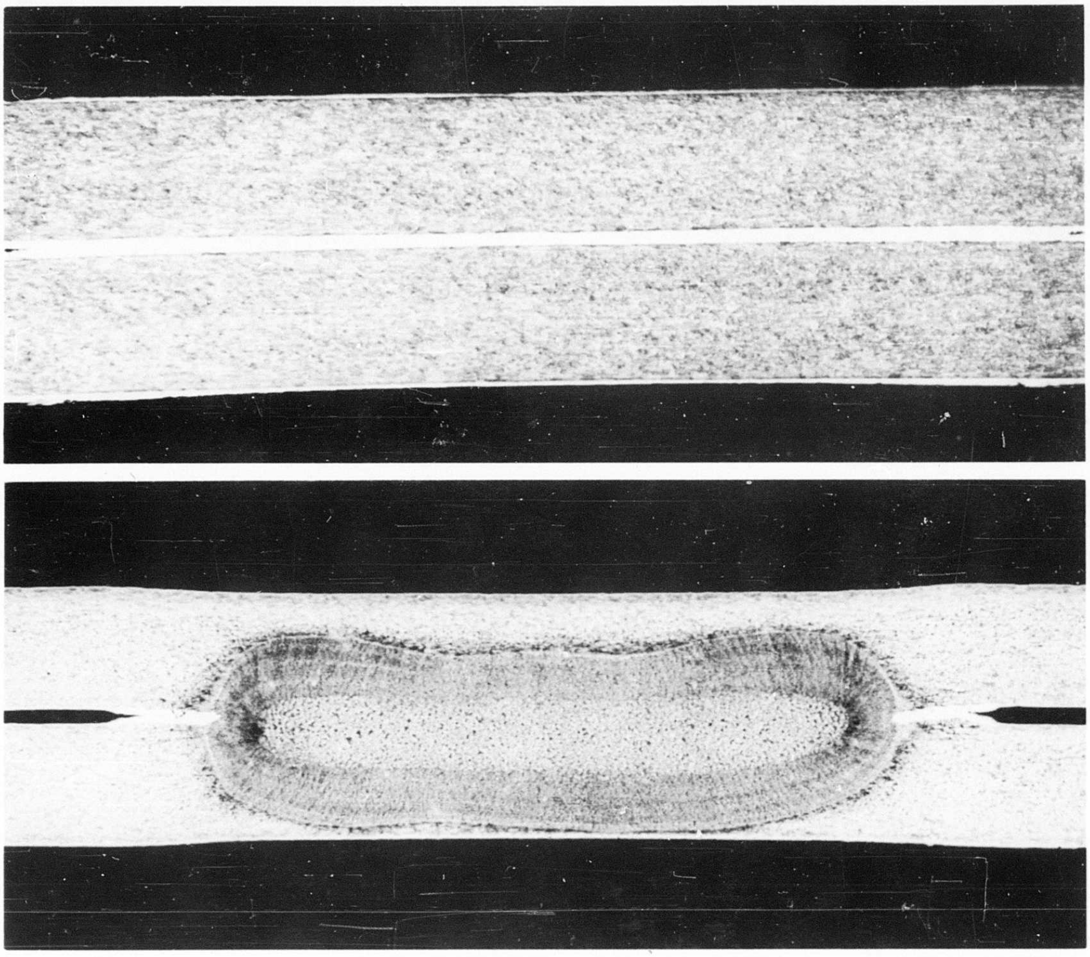
600-watt welder



4-kw welder

Figure 3

COMMERCIAL ULTRASONIC WELDING EQUIPMENT



A

B

A. Typical Microstructure of Ultrasonic Weld in 0.050-inch 2024-T3 Alclad Aluminum Alloy

B. Typical Microstructure of Resistance Spotweld in 0.040-inch 2024-T3 Alclad Aluminum Alloy

Figure 4

	Cu	Au	Mo	Ni	Re	Ag	Mild Steel	Stainless Steel	Ta	Ti	W
Cu	X	X	X	X	X	X	X	X	X	X	X
Au		X		X		X	X	X			
Mo			X	X	X			X	X	X	X
Ni				X	X	X	X	X	X	X	X
Re					X			X	X	X	X
Ag						X	X	X			
Mild Steel							X	X			
Stainless Steel								X	X	X	X
Ta									X	X	X
Ti										X	X
W											X

Figure 5

SIMILAR AND DISSIMILAR METAL COMBINATIONS REQUIRED TO BE ULTRASONICALLY WELDED UNDER THE PROGRAM

Figure 6

INSTRON TESTING MACHINE

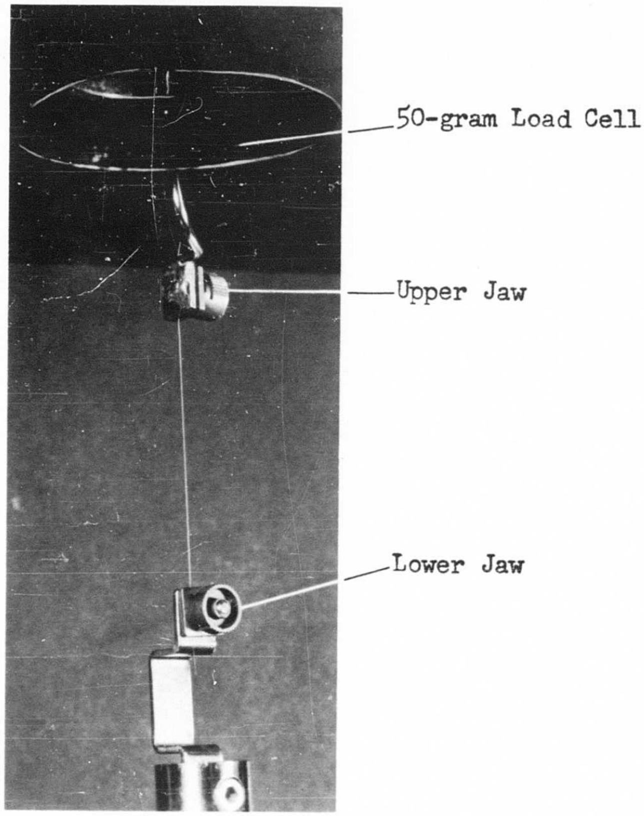


Figure 7

JAWS FOR TENSILE-TESTING FINE, LOW-STRENGTH WIRES

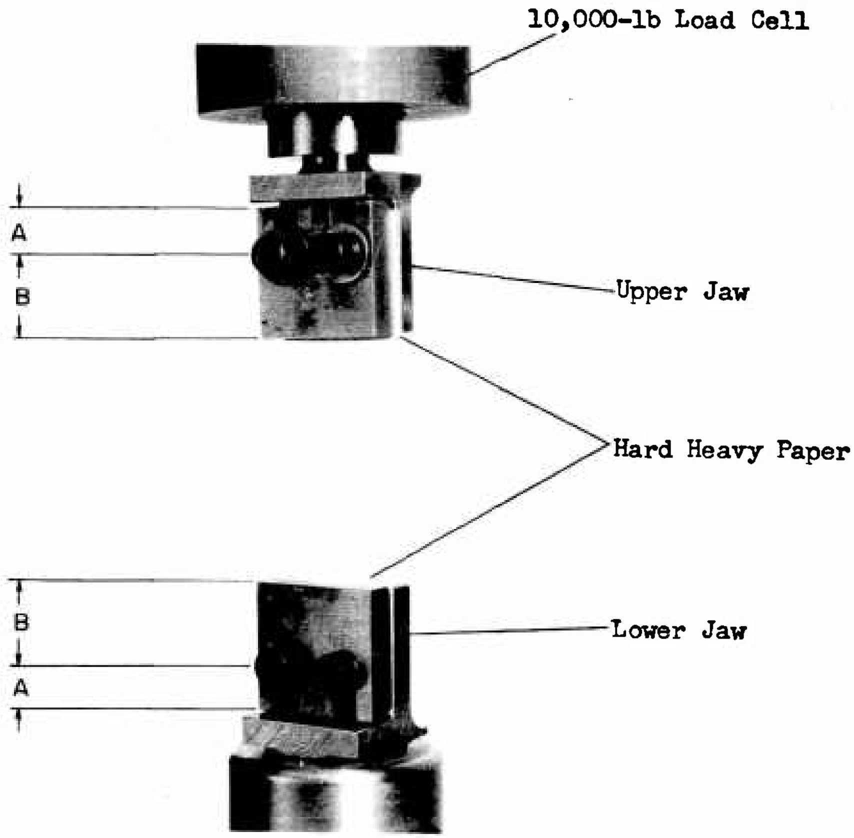


Figure 8

JAWS FOR TENSILE-TESTING FINE, HIGH-STRENGTH WIRES

$A < B$ assures progressive gripping without indentation on the "B" side.

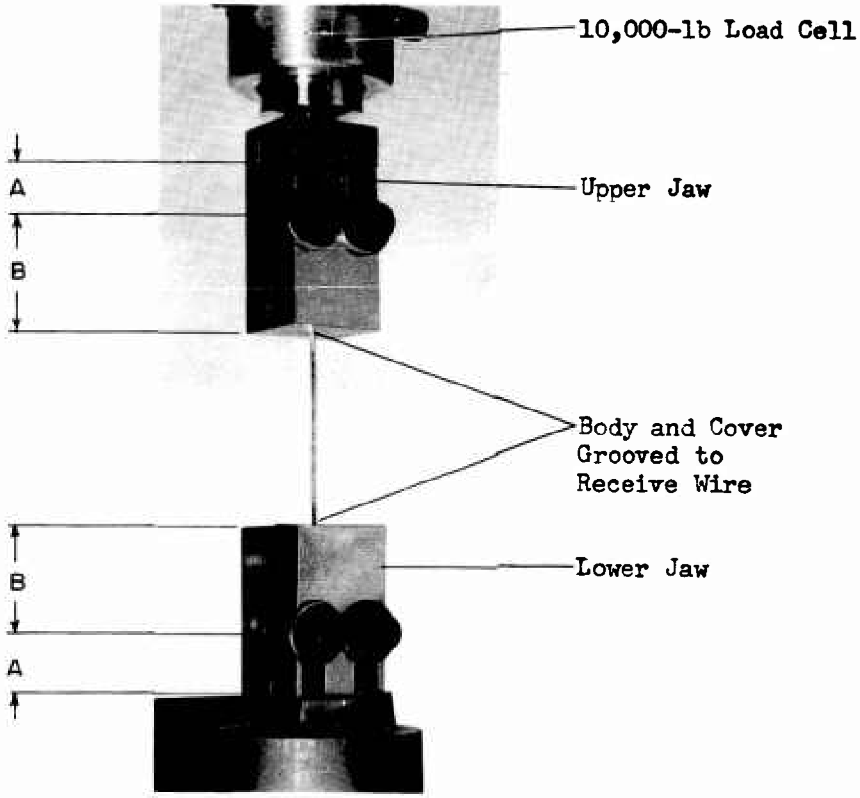


Figure 9

JAWS FOR TENSILE-TESTING 0.060-INCH DIAMETER WIRES

$A < B$ provides progressive gripping

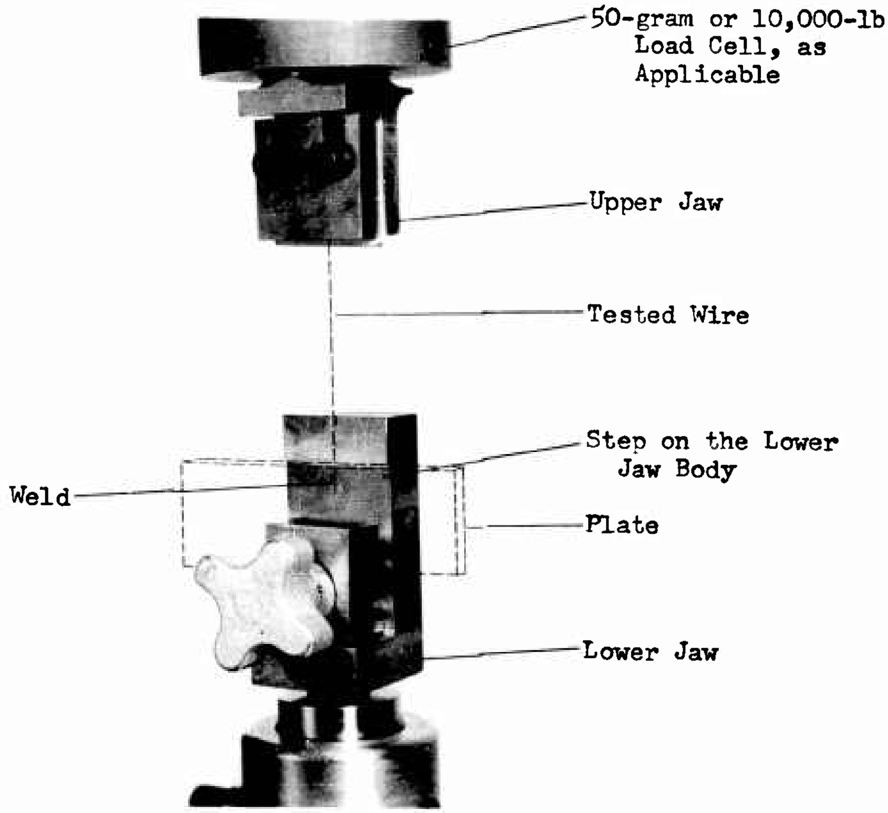


Figure 10

JAWS FOR TENSILE-SHEAR TESTING OF SMALL-DIAMETER HIGH-STRENGTH WIRES WELDED TO COUPONS

(For fine, low-strength wires, upper jaw from Figure 7 will be used.)

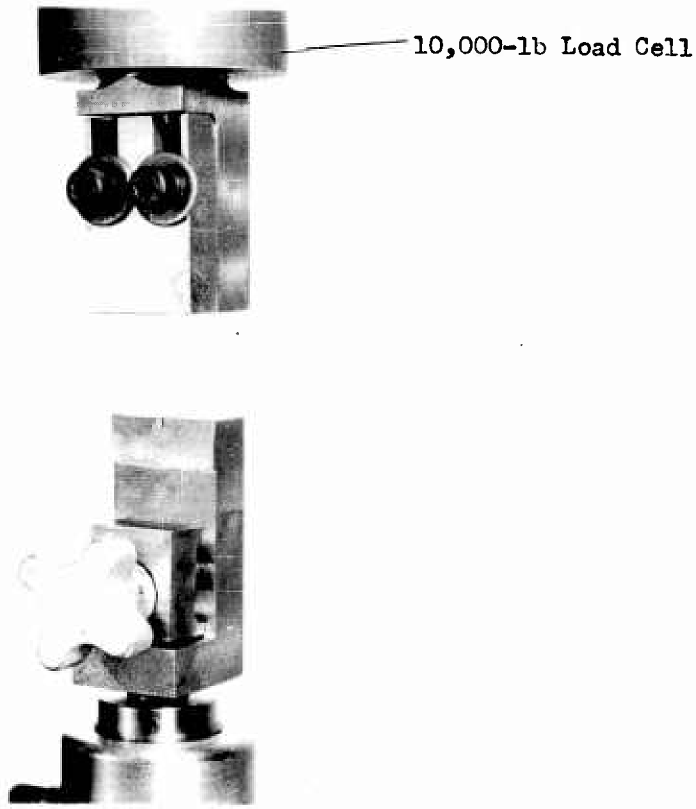


Figure 11

JAWS FOR TENSILE-SHEAR TESTING
0.060-INCH WIRES WELDED TO COUPONS

(Upper jaw from Figure 9)

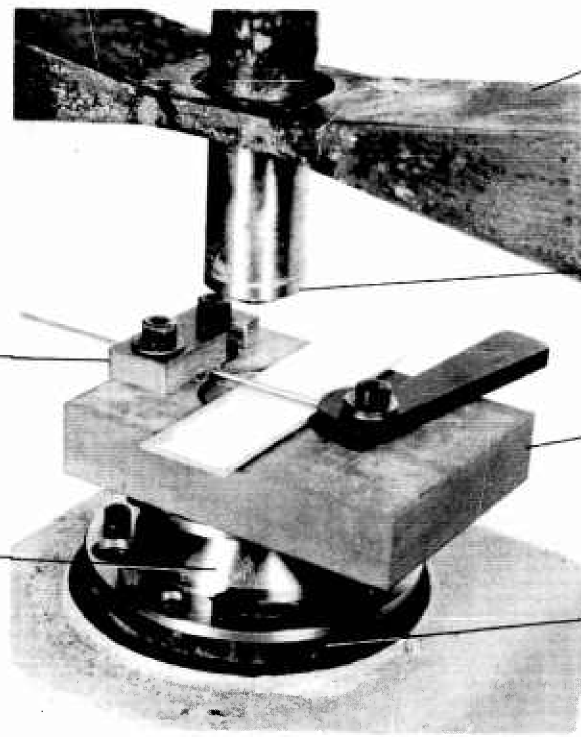


Figure 12

WELDING FIXTURE ON 4-KW SPOT WELDER

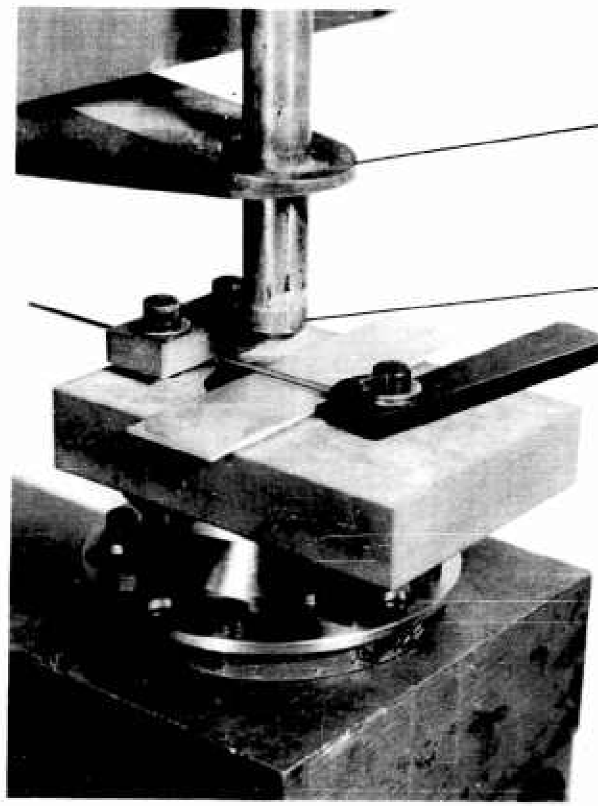


Figure 13

WELDING FIXTURE ON 600-WATT SPOT WELDER

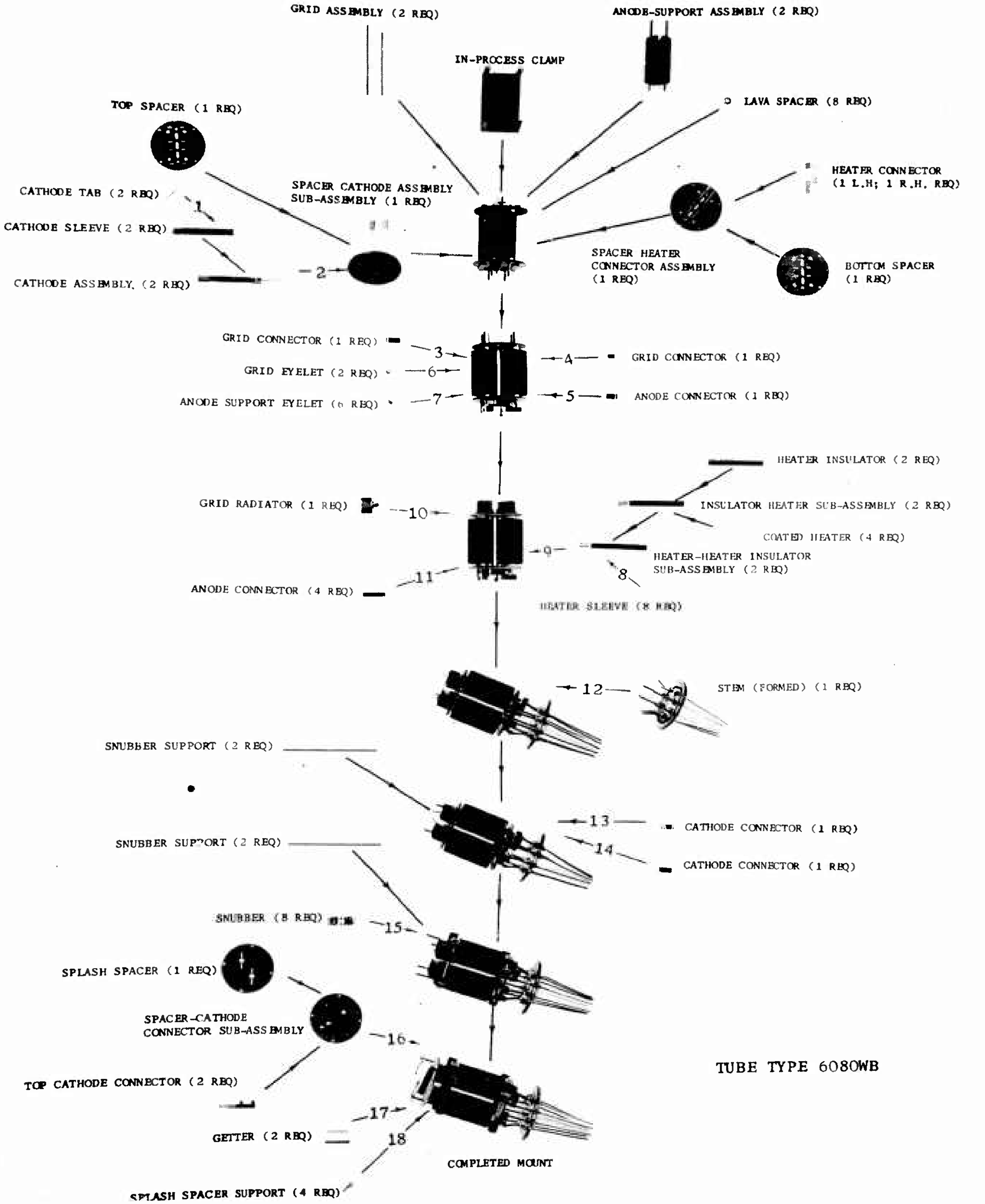
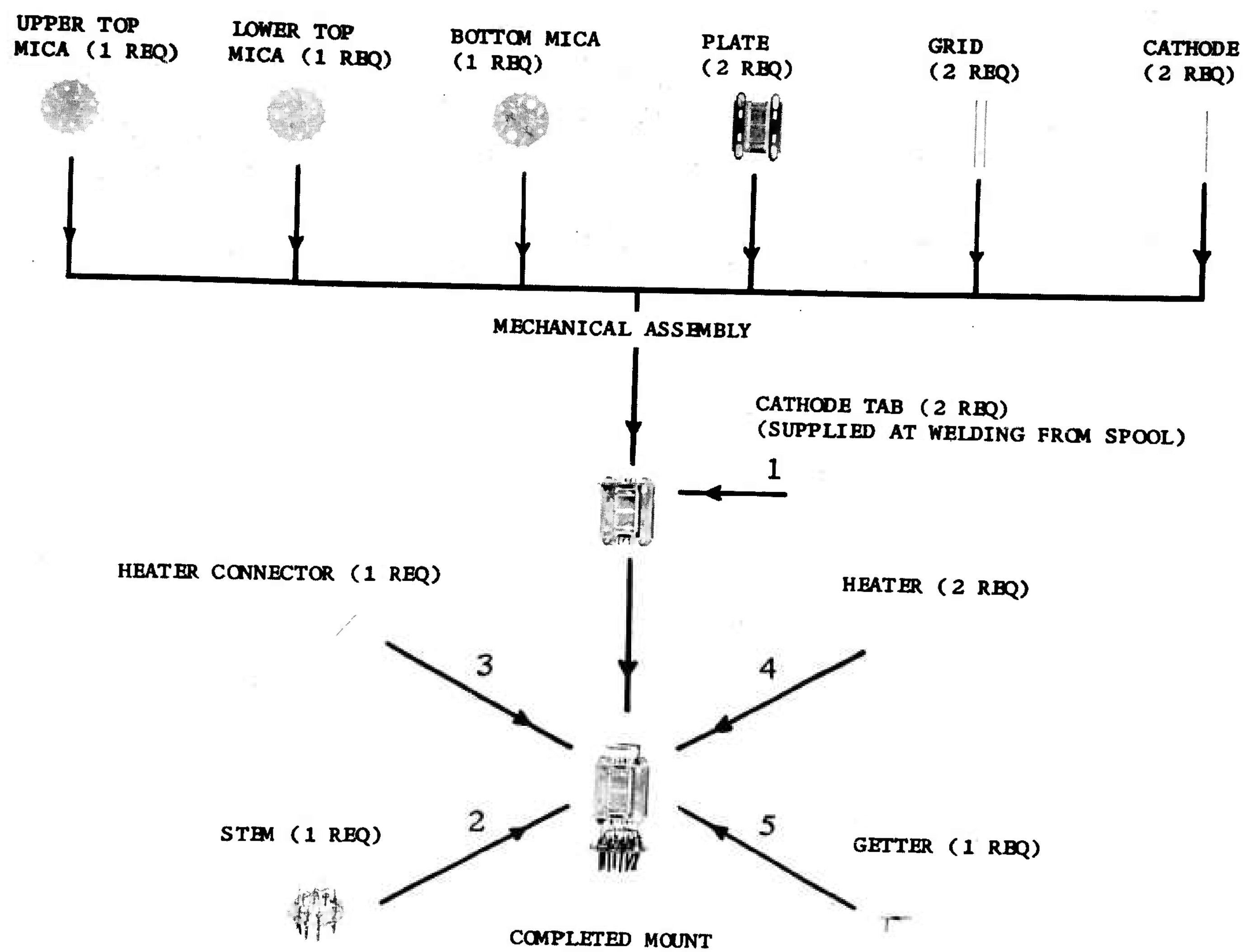


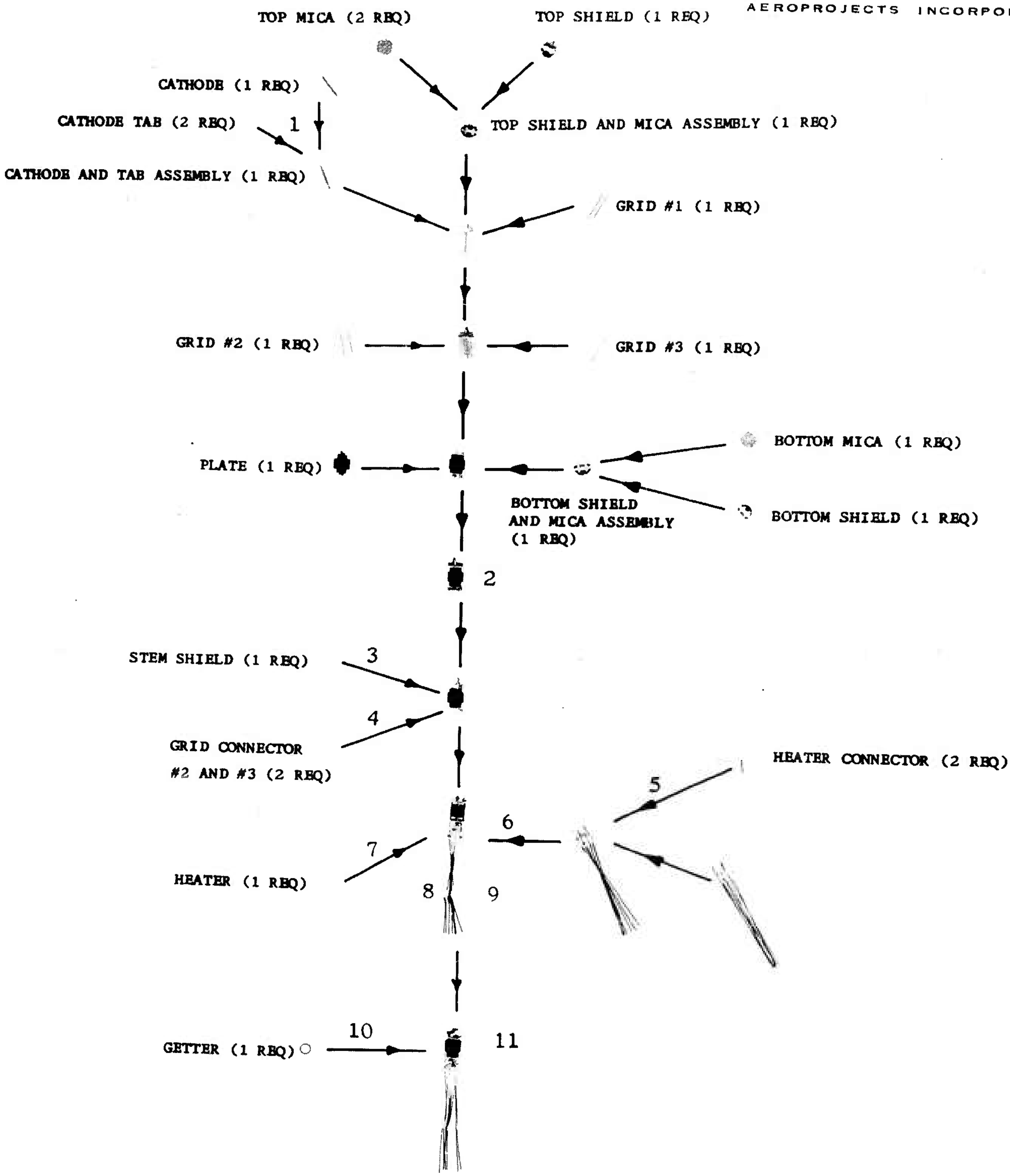
Figure 14
TUBE ASSEMBLY SEQUENCE



TUBE TYPE 5814WB

Figure 15

TUBE ASSEMBLY SEQUENCE



TUBE TYPE 6205

Figure 16

TUBE ASSEMBLY SEQUENCE

Table 1

AVAILABILITY OF MINIMUM-SIZE WIRE (DIAMETER, INCHES)

Companies Contacted	Copper	Gold	Molyb-denum	Nickel "A"	Rhenium	Silver	Mild Steel	Stain-less Steel	Tanta-lum	Titanium	Tungsten
Driver-Harris	-	-	-	0.001	-	-	-	-	-	-	-
Westinghouse Elec.	-	-	0.002	-	-	-	-	-	-	-	0.0003
Little Falls Alloys	-	-	-	-	-	-	-	-	-	-	-
Techalloy Inc.	-	-	-	0.003	-	-	-	0.003	-	-	-
Sigmund Cohn	$\boxed{0.0005}$	$\boxed{0.0003}$	-	$\boxed{0.0005}$	-	0.0015	-	$\boxed{0.001}$	-	$\boxed{0.001}$	$\boxed{0.0003}$
Electric Wire Co.	0.001	0.0015	0.0015	0.0015	-	$\boxed{0.0015}$	$\boxed{0.0015}$	0.0015	-	0.001	0.001
American Silver Co.	-	-	-	-	-	-	-	-	-	-	-
Sylvania Electric	-	-	0.001	-	-	-	-	-	-	-	0.0003
Chase Brass & Copper	-	-	-	-	$\boxed{0.005}$	-	-	-	-	-	-
J. Bishop & Co.	-	-	-	-	-	-	-	-	-	-	-
Kassel Export Co.	0.0005	-	$\boxed{0.0008}$	-	-	-	-	-	-	-	0.0003
Wilbur B. Driver	-	-	-	-	-	-	-	-	-	-	-
Englehard Industries	-	0.0003	-	-	-	$\boxed{0.0003}$	-	-	-	-	-
National Standard	-	-	-	-	-	-	0.0025	-	-	-	-
Wah Chang Corp.	-	-	0.001	-	-	-	-	-	-	-	0.001
International Wire	-	-	-	0.001*	-	0.004*	-	0.001*	-	-	-
Fansteel Metal	-	-	-	-	-	-	-	-	$\boxed{0.003}$	-	-
Titanium Corp.	-	-	-	-	-	-	-	-	-	0.015	-

\- Quote not given

* Special order

$\boxed{}$ Purchase selections

Table 2

MINIMUM-SIZE WIRE PURCHASED

	0.0003 inch	0.0005 inch	0.0008 inch	0.001 inch	0.0015 inch	0.003 inch	0.005 inch
Gold	x						
Tungsten	x						
Silver	x						
Copper		x					
"A" Nickel		x					
Molybdenum			x				
Stainless Steel				x			
Titanium				x			
Mild Steel					x		
Tantalum						x	
Rhenium							x

Table 3

PARENT-METAL STRENGTHS OF WIRES

Material	Gage (inch)	Testing Fixture Figure Number	Actual UTS*
Copper	0.0005	7	6.15 gms
Nickel	0.0005	7	6.3 gms
Titanium	0.001	7	52.5 gms
Tungsten	0.0003	7	16.3 gms
Mild Steel	0.0015	8	0.26 lbs
302 S Steel	0.001	8	0.333 lbs
Tantalum	0.003	8	0.48 lbs
Copper	0.064	9	114 lbs
Nickel	0.060	9	159 lbs
Tantalum	0.062	9	145 lbs
Titanium	0.063	9	256 lbs
Silver	0.060	9	76 lbs
Gold	0.060	9	53 lbs

* Average of Three Specimens

Table 4

DESCRIPTION OF WELDING JUNCTURES

TUBE TYPE 6080WB

Key Nos.	Component	to Component	Gage (inch)	Material	to Gage (inch)	Material	No. of Welds
1	Cathode tab	Cathode sleeve	0.005 x 0.020	"A" Nickel	0.0025	Inco 220 Nickel	2
2	Cathode tab	Itself	0.005 x 0.020	"A" Nickel	0.005 x 0.020	"A" Nickel	2
3	Grid connector	Grid	0.005	"A" Nickel	0.050 Dia	Soft Chrome Copper	1
4	Grid connector	Grid	0.005	"A" Nickel	0.050 Dia	Soft Chrome Copper	1
5	Anode connector	Anode support	0.005	"A" Nickel	0.062 Dia	1/2H "D" Nickel	1
6	Grid eyelet	Grid	0.005-0.008	Nickel	0.050 Dia	Soft Chrome Copper	2
7	Anode eyelet	Anode support	0.005-0.008	Nickel	0.062 Dia	1/2H "D" Nickel	6
8	Heater sleeve	Heater	0.0025 wall	Seamless tubing, "A" Nickel	0.00385 Dia	Tungsten	8
9	Heater sleeve	Heater connector	Flattened tubing	"A" Nickel	0.007	"A" Nickel or Nickel plated steel	8
10	Grid radiator	Grid	0.005	Carbonized Nickel-Duocarb	0.050 Dia	Soft Chrome Copper	4
11	Anode connector	Anode support	0.005	"A" Nickel	0.062 Dia	1/2H "D" Nickel	1
12	Stem leads	Heater connector	0.040 or 0.050 Dia	Nickel lead	0.007	"A" Nickel, nickel-plated steel	2
	Stem leads	Grid connectors	0.040 or 0.050 Dia	Nickel lead	0.005	"A" Nickel	2
	Stem leads	Anode connectors	0.040 or 0.050 Dia	Nickel lead	0.005	"A" Nickel	2

(Concluded on Next Page)

Table 4 (Concluded)

DESCRIPTION OF WELDING JUNCTURES

TUBE TYPE 6080WB

Key Nos.	Component	to Component	Gage (inch)	Material	to Gage (inch)	Material	No. of Welds
13	Cathode connector	Stem lead	0.005	"A" Nickel	0.040 or 0.050 Dia	Nickel lead	1
	Cathode connector	Snubber support	0.005	"A" Nickel	0.040 Dia	1/2H "D" Nickel	1
14	Cathode connector	Stem lead	0.005	"A" Nickel	0.040 or 0.050 Dia	Nickel lead	1
	Cathode connector	Snubber support	0.005	"A" Nickel	0.040 Dia	1/2H "D" Nickel	1
15	Snubber	Snubber support	0.008	Inconel-Hard Temper	0.040 Dia	1/2H "D" Nickel	16
16	Top Cathode connector	Snubber support	0.005	"A" Nickel	0.040 Dia	1/2H "D" Nickel	2
	Top Cathode connector	Cathode tab	0.005	"A" Nickel	0.005 x 0.020	"A" Nickel	2
17	Getter	Snubber support	0.035 Dia	"D" Nickel	0.040 Dia	1/2H "D" Nickel	2
18	Splash spacer support	Snubber support	0.005	"A" Nickel	0.040 Dia	1/2H "D" Nickel	4
						Total Number of Welds	72

Table 5

DESCRIPTION OF WELDING JUNCTURES

TUBE TYPE 5814WB

Key Nos.	Component	to Component	Gage (inch)	Material	to Gage (inch)	Material	No. of Welds
1	Cathode Tab	Cathode	0.003 x 0.010	Nilvar	0.00225 wall	Cathalloy A33 tube	2
2	Stem lead	Plate	0.020 Dia	"A" Nickel	0.010	Alclad Iron	2
	Stem lead	Grid	0.020 Dia	"A" Nickel	0.025 Dia	Nipron	2
	Stem lead	Cathode tab	0.020 Dia	"A" Nickel	0.003 x 0.010	Nilvar	2
3	Heater Connector	Stem lead	0.017 Dia	Nichrome	0.020 Dia	"A" Nickel	1
	Heater Connector	Heater	0.017 Dia	Nichrome	0.0015 Dia	Tungsten	2
4	Heater	Stem leads	0.0015 Dia	Tungsten	0.020 Dia	"A" Nickel	2
5	Getter	Plate	0.025 Dia	Copper Flashed Steel	0.010	Alclad Iron	1

Total Number of Welds 14

Table 6

DESCRIPTION OF WELDING JUNCTURES

TUBE TYPE 6205

Key Nos.	Component to	Component	Gage (inch)	Material to	Gage (inch)	Material	No. of Welds
1	Cathode tab	Cathode	0.002 x 0.006	Nilvar	0.0025-0.0035	220 Nickel Alloy	2
2	Cathode tab	Top shield	0.002 x 0.006	Nilvar	0.005	Nickel-plated Steel	1
	Cathode tab	Bottom shield	0.002 x 0.006	Nilvar	0.005	Nickel-plated Steel	1
3	Stem shield	Bottom shield	0.005	330 Nickel	0.005	Nickel-plated Steel	1
4	#2 Grid	Grid connector	0.01515 Dia	"D" Nickel	0.003 x 0.010	"D" Nickel	1
	#3 Grid	Grid connector	0.020 Dia	Nickel	0.003 x 0.010	"D" Nickel	1
5	Heater connector	Stem lead	0.005 x 0.020	"A" Nickel	0.0179 Dia	"A" Nickel	2
6	Bottom shield	Stem lead	0.005	Nickel-plated Steel	0.0179 Dia	"A" Nickel	2
7	Heater	Heater connector	0.0019 Dia	Tungsten	0.005 x 0.020	"A" Nickel	2
8	#1 Grid	Stem lead	0.01515 Dia	"D" Nickel	0.0179 Dia	"A" Nickel	1
9	Plate	Stem lead	0.005	Alclad Iron	0.0179 Dia	"A" Nickel	1
10	Getter	Top shield	0.0196	Nickel-plated steel	0.005	Nickel-plated Steel	1
11	Grid connector	Stem leads	0.003 x 0.010	"D" Nickel	0.0179 Dia	"A" Nickel	2

Total Number of Welds 18

Table 7

WELD FAILURES* IN MANUFACTURING TUBE TYPE 6080WB

Total No. Mfg.	Open Filament-Heater Connection	Open Welds	Totals	Percent Total
131	-	3	3	2.3
535	8	10	18	3.4
242	2	8	10	4.1
1116	19	56	75	6.7
2023	29	77	106	5.2

* Test Reports on Finished Tubes During a 4-Week Period

LIST OF REFERENCES

1. Rhines, F. N. et al., "Study of Changes Occurring in Metal Structure During Ultrasonic Welding." Summary Report TP 82-162, University of Florida, Gainesville, Florida, April 1962.

2. Peterson, J. M., H. L. McKaig, and C. F. DePrisco, "Ultrasonic Welding in Electronic Devices," 1962 IRE International Convention Record.

3. Jones, J. B., N. Maropis, J. G. Thomas, D. Bancroft, "Fundamentals of Ultrasonic Welding, Phase I." Research Report 59-105, Navy Contract NOas 58-108-c, May 1959.

4. Jones, J. B., N. Maropis, J. G. Thomas, and D. Bancroft, "Fundamentals of Ultrasonic Welding, Phase II." Research Report 60-91, Navy Contract NOa(s) 59-6070-c, December 1960.

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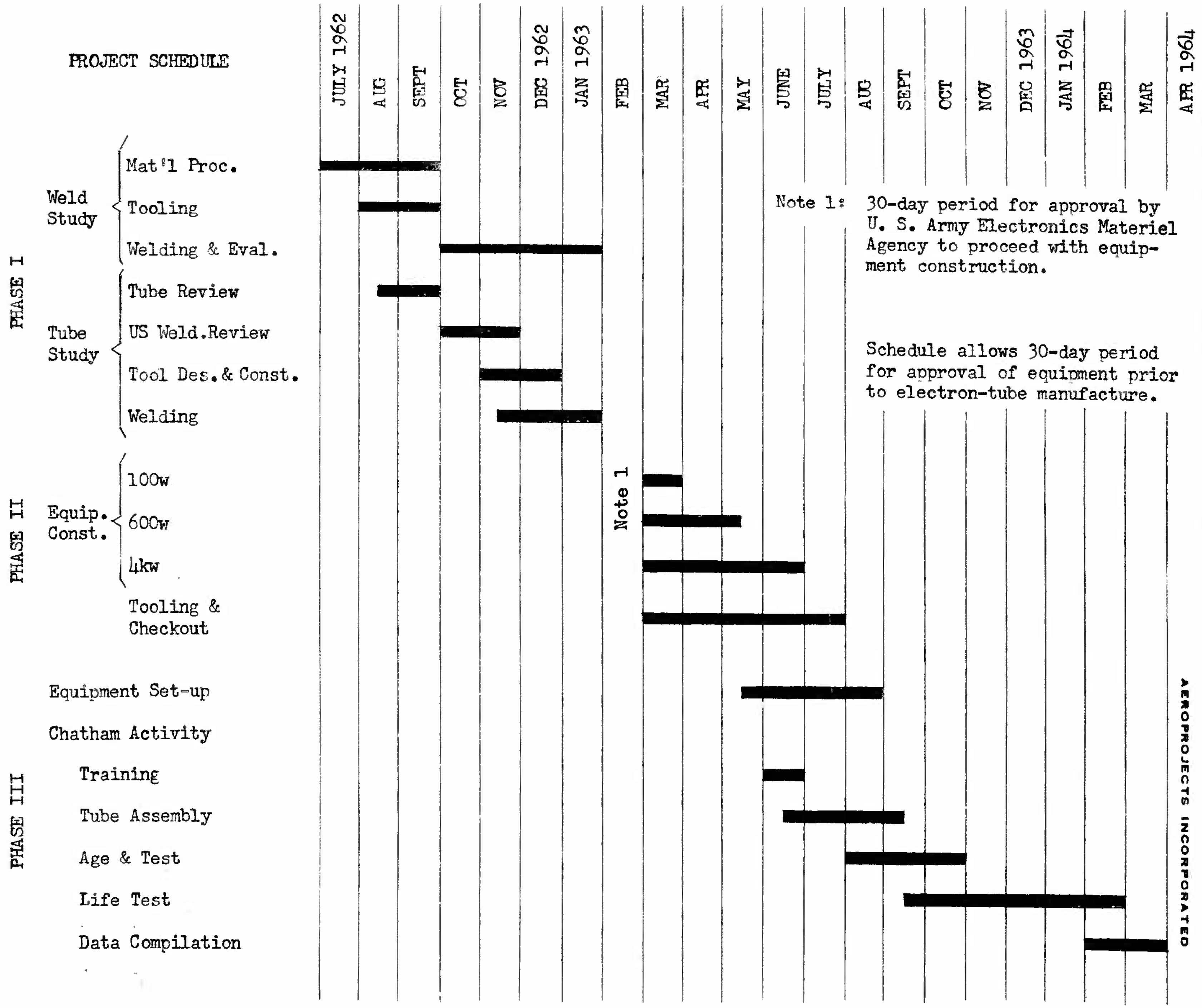
1. Rhines, F. N. et al., "Study of Changes Occurring in Metal Structure During Ultrasonic Welding." Summary Report TP 82-162, University of Florida, Gainesville, Florida, April 1962.

2. Peterson, J. M., H. L. McKaig, and C. F. DePrisco, "Ultrasonic Welding in Electronic Devices," 1962 IRE International Convention Record.

3. Jones, J. B., N. Maropis, J. G. Thomas, D. Bancroft, "Fundamentals of Ultrasonic Welding, Phase I." Research Report 59-105, Navy Contract NOas 58-108-c, May 1959.

4. Jones, J. B., N. Maropis, J. G. Thomas, and D. Bancroft, "Fundamentals of Ultrasonic Welding, Phase II." Research Report 60-91, Navy Contract NOa(s) 59-6070-c, December 1960.

PROJECT SCHEDULE



IDENTIFICATION OF TECHNICAL PERSONNEL

Personnel working on the problem who made technical contributions, and the manhours of work performed by each during this report period.

J. Byron Jones, President and Director of Research

B. S. in Mechanical Engineering from New York University, 1932. His background and experience include several years as instructor in aeronautical engineering; 2-1/2 years in a responsible machine development capacity directing and coordinating various phases of manufacturing improvement; 6 years with Goodyear Aircraft Corporation, Akron, Ohio, serving in a technical directive capacity over about 100 scientific, clerical, and shop personnel, and supervising such activities as the design, development, and testing of aircraft and missiles, as well as aerodynamic, electronic, and physics research; carried out extensive research in the application of ultrasonics, including nondestructive testing. Was subsequently appointed Manager of Goodyear's Aerophysics Departments and directed the efforts of up to 125 scientific employees in connection with Air Force and Navy missile projects.

Mr. Jones was responsible for establishing Aeroprojects in 1948, and he personally directs the research programs undertaken by this company. Much of our progress in the application of ultrasonic energy at high power levels is the result of the development of special transducer-couplings. During the past 13 years Mr. Jones has been directly connected with the activities in this unique field of engineering, and his experiences and ingenuity have contributed considerably to the development of high-powered ultrasonic transducer-couplings.

He is a member of the American Welding Society, the Acoustical Society of America, the Institute of Aeronautical Sciences, and the Franklin Institute. Within the past several years, a number of articles on various ultrasonic applications have appeared in the literature under Mr. Jones' authorship, and he has presented invited papers on ultrasonic welding and its applications for a number of scientific organizations. Mr. Jones is chairman of the AWS Welding Handbook Subcommittee on Ultrasonic Welding.

William N. Rosenberg, Mechanical Engineer

B. S. in Mechanical Engineering from Drexel Institute of Technology, 1949. Mr. Rosenberg has had more than 10 years' experience in the design and development of industrial machinery. From 1955 to 1959 he served as Chief Engineer in the Automatic Machinery Division of the Selas Corporation of America. In that post he supervised the design of custom-built heat-processing equipment, and worked closely with the Sales Department in the preparation of complex proposals and in customer contact on all phases of the various projects. For 4 years he was engaged as Mechanical Development Engineer for the International Resistance Company, where he was responsible for the development of automatic machinery to be used in the high-speed production of electrical resistors and resistor components of all types. This work included supervision of draftsmen, technicians, and shop men. He was employed for 2 years by Sharp & Dohme, Inc., in the design of special machinery for the manufacture and packaging of pharmaceuticals and biologicals.

Mr. Rosenberg participated on the American Society for Metals Committee concerned with preparation of the "Furnace Parts and Fixtures" section for the 1959 edition of the Metals Handbook.

At Aeroprojects, Mr. Rosenberg was responsible for Supervision of the Ultrasonic Welding Laboratory, and more recently has undertaken a field study of ultrasonic welding equipment presently in industrial use. The results of this study will significantly affect the direction of future development in ultrasonic welding equipment.

Josef Koziarski, Ultrasonic Welding Laboratory Director

Degree in Aeronautical Engineering from Ecole National Superieure d'Aeronautique, Paris, France, 1930, with graduate studies in metallurgy, corrosion, welding, fatigue, helicopter aerodynamics, and ultrasonic inspection methods. In addition, he has attended and graduated from various military schools and staff colleges in Poland and England, as well as the United States Command and General Staff School at Fort Leavenworth, Kansas.

During his early years, Mr. Koziarski was associated with the Polish Air Force's Technical Training Center and spent 3 years directing general and technological education at the Air Force Technical College in Warsaw. He also worked with the Cracow Academy of Mines and the Polish Committees on Corrosion and Standards. During World War II, he escaped with the Polish Air Force to France and later to England, and after the war was associated for 2 years with the British Welding Research Association. He came to the United States in 1948, and for 10 years was associated with Piasecki Helicopter Corporation, later Vertol Aircraft Corporation, where he was responsible for various development activities in welding design and ultrasonic inspection. He subsequently spent 3 years with the Martin Company, Denver, Colorado, engaged in various research and development activities associated with welding, corrosion, and metallurgy. While there, he developed special techniques for utilizing ultrasonic welding in the fabrication of components for the SNAP-1A.

In 1957, Mr. Koziarski received Gold and Silver Awards from the Steel Founder's Association of America for the development of special metal castings. In 1960 he was given a citation by Materials in Design Engineering a variety of papers in the United States, United Kingdom, Poland,

and Sweden, on welding, ultrasonic inspection, and military science. He is a member of the Royal Aeronautical Society, the Institute of Welding of the United Kingdom, the American Welding Society, and the American Society for Metals.

Mr. Koziarski joined Aeroprojects in 1961 as Director of our Ultrasonic Welding Laboratory, where his duties include the development of techniques for ultrasonic joining of new material combinations and geometries.

John G. Thomas, Metallurgist

B. S. in Metallurgical Engineering from Towne Scientific School of the University of Pennsylvania, 1952, and currently working toward an advanced degree in Metallurgical Engineering. While an undergraduate student at the University, Mr. Thomas was associated with the Frankford Arsenal in Philadelphia, engaged in research projects which included stress-strain relationships of alloy steels subjected to compression, the determination of crystal structure of tin-selenium compounds, and the identification of phases in iodide-process zirconium.

Mr. Thomas is in charge of the Metallurgical Laboratory at Aeroprojects and, since joining the company in 1952, has carried out research on a number of phases of the application of ultrasonics to metallurgy. He has gained extensive experience in ultrasonic metal-treatment techniques applied to exotic metals such as thorium, titanium, palladium, niobium, tantalum, and molybdenum. He has been involved with the development of ultrasonic welding of pure crystal materials such as germanium and silicon, as well as the development of equipment for ultrasonic treatment of powdered metal compacts. He is in charge of Aeroprojects' work on radiography, electron micrography, and the use of radioactive tracers.

Mr. Thomas is a member of the American Society for Metals and the American Institute for Mining, Metallurgical, and Petroleum Engineers.

Alfred L. Fuchs, Design Engineer

Aeronautical Engineering studies at the Academy of Aeronautics, La Guardia Field, New York, 1949. He has been employed in the engineering design field for the past 9 years. He was a Junior Design Engineer at the Goodyear Aircraft Corporation for 1-1/2 years, specializing in airship power plant and equipment installation. For 2 years he served as a Design Engineer and Group Checker at the Piasecki Helicopter Corporation, Morton, Pennsylvania, which included work on all design phases of the HVP and H-21 helicopters.

During the past 8 years, Mr. Fuchs has been employed at Aeroprojects as Design Engineer, concerned with the design of laboratory and pilot-plant equipment for the company's development programs, as well as with the design of commercial ultrasonic metal-joining equipment. His responsibilities include fabrication liaison with Aeroprojects experimental machine shops.

Carmine F. DePrisco, Chief Electronics Engineer

His education was in Electrical Engineering at Drexel Institute of Technology, with subsequent special RCA Courses in Radio, Television, and Radar Design and Engineering. Mr. DePrisco has been engaged in electrical and electronic activities for about 30 years and has kept abreast of the growing technology in the field. During World War II, he spent 4 years with RCA Victor in Camden, New Jersey, supervising the development and test of military aircraft electronics equipment; later experience includes 4 years at the University of Pennsylvania in the design and development of electronic control and measuring equipment, and one additional year with RCA Victor.

Since joining Aeroprojects in 1951, Mr. DePrisco has been responsible for the development and test of electronic ultrasonic equipment, as well as electronic control and measuring devices, for Aeroprojects' research programs. He has played a leading role in the design, development, fabrication and test of ultrasonic transducer-couplings for a wide variety of applications, particularly for ultrasonic welding, and is co-inventor on a number of patented apparatuses. He has been responsible for the development of new, highly reliable ultrasonic generating equipment of the electronic and motor-generator types and recently of the very new solid-state type of generator. His ingenuity has also been demonstrated in the design and assembly of specific-purpose electronic measuring and testing devices for use over the whole spectrum of Aeroprojects' research activities. Mr. DePrisco is a member of the Institute of Radio Engineers and the Franklin Institute.

George C. Sekula - Junior Engineer

B. S. in Civil Engineering, Villanova University, School of Engineering, 1959. For one year immediately following graduation, and during undergraduate years, Mr. Sekula worked in the construction field, specializing in design engineering. Prior to joining the staff of Aeroprojects, he served for two years as a technical editor with the Chilton Company, Philadelphia, Pennsylvania, publishers of a group of internationally recognized technical trade journals. He acted as Technical Associate Editor for such publications as The Iron Age, The National Metalworking Weekly, and Iron Age Metalworking International.

TECHNICAL PERSONNEL
Chatham Electronics
Livingston, N. J.

B. F. Steiger, Director of Electron Tube Engineering

E. E. Cornell University 1926; more than 30 years experience in the electronic field, participating in the development of ultraviolet lamps; vacuum tubes, deposition of screen phosphors and projection type cathode ray tubes; modulation tubes; and mercury rectifiers. In charge of development and design of special purpose and ruggedized tubes for military application.

N. Helmstetter, Senior Methods Engineer

Catholic University of America - B.E.E. Seton Hall University and Newark College of Engineering on post graduate work in Mathematics. Spent six years as a Methods Engineer and Cost Analysist, and four years on electro-mechanical design in the radio tube industry.

TECHNICAL MAN-HOURS
EXPENDED DURING THIS REPORT PERIOD

NAME	PROJECT POSITION	HOURS EXPENDED THIS REPORT PERIOD
W. N. Rosenberg	Project Supervisor	123
J. Byron Jones	Consultant	19
J. Koziarski	Director Welding Lab	53
J. G. Thomas	Metallurgist	55-1/2
G. Sekula	Junior Engineer	16
A. L. Fuchs	Chief Design Engineer	25-1/2
C. DePrisco	Chief Electronics Engineer	1-1/2

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